SEISMIC HAZARD ZONE REPORT 075

SEISMIC HAZARD ZONE REPORT FOR THE SANTA PAULA PEAK 7.5-MINUTE QUADRANGLE, VENTURA COUNTY, CALIFORNIA

2003

DEPARTMENT OF CONSERVATION
California Geological Survey

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Santa Paula Peak 7.5-Minute Quadrangle, Ventura County, California. The map displays the boundaries of zones of required investigation for liquefaction and earthquake-induced landslides over an area of approximately 37 square miles at a scale of 1 inch = 2,000 feet. The portion of the northern half of the quadrangle that lies within the Los Padres National Forest was not evaluated for zoning.

The Santa Paula Peak Quadrangle lies in southern Ventura County and includes the northernmost part of the City of Santa Paula and the unincorporated community of Sulphur Springs. The northern part of the quadrangle is dominated by steep mountainous terrain of the Topatopa Mountains. The ridge crests of Sulphur Mountain and Santa Paula Ridge trend roughly east-west across the center of the map area. The southern slopes of Sulphur Mountain and Santa Paula Ridge occupy the southern half of the quadrangle. Elevations range from approximately 400 feet above sea level in the southern part to 6,367 feet in the northwest near Topatopa Bluff. The most important drainage course is Santa Paula Creek. Major tributaries include Sisar Creek, which drains the western Topatopa Mountains and eastern Upper Ojai Valley, East Fork and La Broche and Echo Falls canyons, which drain the Topatopa Mountains, and Anlauf Canyon and Mud Creek, which flow southwestward from Santa Paula Ridge. Access to the area is via State Highways 150 and 126. Residential development is concentrated in the valley areas. Additional land use includes oil operations, cattle grazing, orchards, and parkland.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years.

In the Santa Paula Peak Quadrangle the liquefaction zone is restricted to the bottoms of canyons. The combination of mountainous topography developed upon a variety of weak rock units has produced widespread and abundant landslides. These conditions contribute to an earthquake-induced landslide zone that covers about 62 percent of the area evaluated in the quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
945 Bryant Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Santa Paula Peak 7.5-Minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Santa Paula Peak 7.5-Minute Quadrangle, Ventura County, California

By
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California Department of Conservation
California Geological Survey

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Santa Paula Peak 7.5-Minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking) complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.conservation.ca.gov/CGS/index.htm

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles region was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, including areas in the Santa Paula Peak Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill.

- Ground-water maps constructed to show the historically highest known ground-water levels

- Geotechnical data analyzed to evaluate liquefaction potential of deposits

- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Santa Paula Peak Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Santa Paula Peak Quadrangle covers approximately 62 square miles in southern Ventura County and includes the northernmost part of the City of Santa Paula and the unincorporated community of Sulphur Springs. The City of Santa Paula is located about 10 miles northeast of the county seat at Ventura. Approximately 25 square miles of area in the northern half of the quadrangle was not evaluated for zoning because it lies within Los Padres National Forest.

The northern part of the Santa Paula Peak Quadrangle is dominated by steep mountainous terrain of the Topatopa Mountains. The ridge crests of Sulphur Mountain and Santa Paula Ridge trend roughly east-west across the center of the map area. The rugged southern slopes of Sulphur Mountain and Santa Paula Ridge occupy the southern half of the quadrangle. Elevations range from approximately 400 feet above sea level in the southern part of the map area to 6,367 feet in the northwest near Topatopa Bluff. Santa Paula Peak is 4,957 feet above sea level.

The most important drainage course in the quadrangle is Santa Paula Creek, which flows in a southerly direction through the Topatopa Mountains and between Sulphur Mountain and Santa Paula Ridge before its confluence with the Santa Clara River just south of the quadrangle. Major tributaries to Santa Paula Creek include east-flowing Sisar Creek, which drains the western Topatopa Mountains and eastern Upper Ojai Valley, East Fork and La Broche and Echo Falls canyons, which drain the Topatopa Mountains, and Anlauf Canyon and Mud Creek, which flow southwestward from Santa Paula Ridge. West of Santa Paula Creek, drainage from Sulphur Mountain flows south via Salt Marsh, Adams, and Fagan canyons to the Santa Clara River. East of Santa Paula Creek, drainage from Orcutt and Timber canyons flows south from Santa Paula Ridge to the Santa Clara River.

Access to the area is via State Highways 150 and 126. Highway 150 (Santa Paula – Ojai Road) follows Santa Paula Creek north from Santa Paula and then curves to the west near Sulphur Springs. Highway 126 is located just south of the quadrangle and is the major east-west transportation route along the Santa Clara River Valley. Access to less developed areas is provided by fire roads, ranch roads, and oil field roads.

Residential development is concentrated in the valley areas with scattered development in the canyons, on the hillsides, and along Sulphur Mountain Road on the crest of Sulphur Mountain. Other land use in the area includes oil drilling and production in the Ojai (Silverthread Area), Santa Paula, and Timber Canyon oil fields, cattle grazing, citrus and avocado orchards, parkland, campgrounds, and the campus of Thomas Aquinas College. The northern half of the quadrangle lies within Los Padres National Forest, which includes part of the Sespe Wilderness Area and the Sespe Condor Sanctuary.

GEOLOGY

Bedrock and Surficial Geology

The Quaternary geology used in the liquefaction evaluation of the Santa Paula Peak Quadrangle was obtained both from Dibblee (1990) and William Lettis and Associates (2000). Plate 1.1 displays the more detailed geologic map of the latter. As noted on Plate 1.1, Quaternary deposits are restricted to Santa Paula Creek, Sisar Creek, Timber Canyon, Adams Canyon, as well as a small segment of the Santa Clara River valley in the southeastern corner of the Santa Paula Peak Quadrangle.

Although zoning for liquefaction potential is generally restricted to alluviated lowland areas, a brief summary of the bedrock units exposed in the surrounding highlands is relevant. The nature and distribution of the alluvial materials deposited in basins depends largely on the lithology of bedrock units exposed in adjacent upland regions. For example, erosion of sandstone units widely exposed in mountainous terrain results in the deposition of sediments rich in sand in adjacent valleys, whereas erosion of shale typically results in the deposition of clay and silt.

Three distinct groups of bedrock formations occur within the Santa Paula Peak Quadrangle. These are: (1) Eocene marine shale and sandstone (Juncal Shale, Matilija Sandstone, Cozy Dell Shale, Coldwater Sandstone) exposed over most of the northern half of the quadrangle; (2) nonmarine sandstone of the Oligocene Sespe Formation that crops out along the northeastern border of the quadrangle; and (3) numerous marine sedimentary units that range from Oligocene to Pliocene exposed in the southern half of the quadrangle (Vaqueros Sandstone, Rincon Shale, shale of the Monterey Formation, Sisquoc Shale, claystone of the Pico Formation, Las Posas Sand, and cobble-boulder conglomerate of the Saugus Formation). See the discussion of the bedrock units in Section 2 for more detail.

Quaternary surficial materials consist mainly of older and younger alluvial, alluvial fan, and stream channel deposits in and adjacent to Santa Paula and Sisar creeks and within Timber, Adams, Fagan, Bear, and numerous smaller canyons. Dibblee (1990) divides Quaternary deposits into older alluvium (Qoa), older gravel terrace (Qog), and older fan deposits (Qof), younger alluvium and stream channel deposits (Qa), younger gravelly stream channel deposits (Qg), and fan deposits (Qf). The texture and thickness of these deposits vary considerably among, and even within, individual canyons depending on local bedrock lithologies and prevalent stream energy conditions.

Structural Geology

The Santa Paula Peak Quadrangle lies within the central Ventura Basin in the Transverse Ranges geomorphic province. Rocks in this region have been folded into a series of predominantly west-trending anticlines and synclines associated with thrust and reverse faults. This deformation was caused by regional north-south compression, which began during the late Pliocene and continues today (Yeats, 1989). Regional crustal shortening due to this compression is largely accommodated by the San Cayetano Fault and associated folds and flexural-slip faults in the Santa Paula Peak Quadrangle (Keller and others, 1982). To the west of the quadrangle in the Ojai Valley area, shortening is taken up by a blind-thrust fault and associated folding (Namson and Davis, 1988; Huftile, 1991).

The most important structural feature in the Santa Paula Peak Quadrangle is the San Cayetano Fault, an active, north-dipping reverse fault that extends along the north flank of Ventura Basin from the east end of Ojai Valley to Piru. It displaces Tertiary and Quaternary rocks with as much as 9 kilometers of stratigraphic separation (Rockwell, 1988). The trace of the San Cayetano Fault trends roughly east-west across the center of the Santa Paula Peak Quadrangle and is included in the Official Earthquake Zone prepared by CGS (DOC, 1986; Smith, 1977). Eocene- to Oligocene-age rocks in the upper plate of the San Cayetano Fault are folded into a series of west-northwest-trending synclines and anticlines and are thrust over Miocene and younger rocks to the south.

Major structural elements in the southwest quarter of the Santa Paula Peak Quadrangle, south of the San Cayetano Fault, include the Sisar Fault, Sulphur Mountain anticlinorium, South Sulphur Mountain Fault, and Sulphur Mountain homocline. Miocene strata form the Sulphur Mountain anticlinorium, which is complexly folded and has overturned limbs on both of its flanks. The Sisar Fault is a south-dipping thrust fault that extends along the north side of Sulphur Mountain and is believed to have formed as a backthrust above the main blind thrust fault (Huftile, 1991). The South Sulphur Mountain Fault is a north-dipping reverse fault that forms a pop-up structure along the south side of the crest of Sulphur Mountain (Huftile, 1991). Upper Miocene and Plio-Pleistocene strata form the south-dipping Sulphur Mountain homocline and northern flank of the Santa Clara Syncline in the southwest corner of the quadrangle.

In the southeast quarter of the quadrangle, steeply dipping Plio-Pleistocene strata on the northern flank of the Santa Clara Syncline are overlain unconformably by Late Pleistocene- to Holocene-age alluvial fans that extend down from the San Cayetano Fault into Orcutt and Timber canyons. These fan deposits are cut by eight parallel faults with south side up that show normal displacement where bedding is overturned and reverse displacement where bedding is right side up (Keller and others, 1982). From north to south, the four main faults, which are known collectively as the Orcutt/Timber Canyon faults, are called the Thorpe, Orcutt, Culbertson, and Rudolph faults (Keller and others, 1982). These faults are believed to be bedding-plane faults that undergo displacement during flexural-slip folding of the Santa Clara Syncline (Keller and others, 1982). Although these faults are not considered to be significant earthquake sources, they do have the potential for ground rupture and, therefore, the surface traces of these faults are included in the Official Earthquake Zone prepared by CGS (DOC, 1986; Kahle, 1985).

ENGINEERING GEOLOGY

As previously stated, soils that are generally susceptible to liquefaction are generally late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. Deposits that contain saturated, loose sandy and silty soils are most susceptible to liquefaction. Lithologic descriptions and soil test results reported in geotechnical borehole logs provide valuable information regarding subsurface geology, ground-water levels, and the engineering characteristics of sedimentary deposits.

Of particular value in liquefaction evaluations are logs that report the results of downhole standard penetration tests. Standard Penetration Tests (SPTs) provide a uniform measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 1999). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60 percent using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

GROUND WATER

Depth to ground water is a key factor governing liquefaction hazard. Ground-water saturation reduces the effective normal stress acting on loose, sandy sediments, thus lowering the resistance of sediments to loss of strength when pore-water pressure increases during ground shaking. Liquefaction of subsurface sedimentary layers can result in structure damaging ground failure at the surface through differential settlement or lateral spreading, particularly if the phenomenon occurs at a depth from the surface of less than 40 feet.

Natural processes and human activities over seasons, years, and decades cause large fluctuations in ground-water levels. These fluctuations generally make it impossible to specify what conditions might exist when future earthquakes could cause major ground shaking. To address this uncertainty, CGS develops ground-water maps that show depths to historically shallowest levels recorded from water wells and boreholes drilled over the past century. The evaluations are based on first-encountered water noted in the borehole logs. Water depths from boreholes known to penetrate confined aquifers are not used. The resultant maps, which are based on measurements recorded over the past century or more, differ considerably from conventional ground-water maps that are based on measurements collected during a single season or year.

Depths to historically shallowest ground water in alluviated canyon regions of the Santa Paula Peak Quadrangle are presented on Plate 1.2. Historical ground-water level measurements in canyon areas are generally shallow, commonly less than 10 feet deep. Such shallow ground-water conditions commonly exist in these types of depositional environments because canyon lowlands tend to receive and accumulate heavy runoff and near-surface ground water derived from surrounding highlands.

LIQUEFACTION POTENTIAL

Liquefaction can occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and might fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in CGS evaluations of liquefaction potential is similar to that of Tinsley and others (1985) who apply a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates following criteria adopted by the SMGB (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. CGS's qualitative assessment of liquefaction susceptibility relative to various geologic units is summarized in Table 1.1.

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Qa	sand, silt, clay	canyon floor, stream channel	very loose to loose	Yes
Qg	gravel	stream channel	very loose to loose	Yes
Qf	sand, silt, clay	alluvial fan	loose	Yes
* depending on clay/cobble content, thickness and historic ground-water depth.				

Table 1. 1. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Units.

LIQUEFACTION OPPORTUNITY

Analysis of in-situ liquefaction potential requires assessment of liquefaction opportunity. Liquefaction opportunity is the estimation of the severity of expected future ground shaking over the region at a specific exceedance probability and exposure time (Real, 2002). The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10 percent probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in CGS's analysis of liquefaction potential is the magnitude that contributes most to the calculated PGA for an area.

For the Santa Paula Peak Quadrangle, PGAs of 0.72 to 0.92 g (for alluvium), resulting from a predominant earthquake of magnitude 6.8, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10 percent in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion portion (section 3) of this report for additional discussion of ground motion characterization.

Quantitative Liquefaction Analysis

Quantitative analysis of geotechnical data was not performed because no borehole log records were found within the project area. When available, however, CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the

Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997; Youd and others, 2001). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

The CGS liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test using the minimum $(N_1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Santa Paula Peak Quadrangle is summarized below.

Areas of Past Liquefaction

Although no accounts of liquefaction in the Santa Paula Peak Quadrangle were found in this study, there are reports of liquefaction-like features noted in adjacent areas. For example, excerpts of 1858 topographic survey reports (California Division of Mines and Geology, 1976) describe ground lurch cracks and related features associated with liquefaction observed in the Santa Clara River near the City of San Buena Ventura, about 10 miles downstream from Santa Paula. About 15 miles west of the Santa Paula Peak Quadrangle, lateral spreading possibly associated with liquefaction was mapped adjacent to the Santa Clara River and also within Potrero Canyon by Rymer and others (2001) following the Northridge earthquake. Documented evidence of paleoseismic liquefaction was not found during the course of this study.

Artificial Fills

In the Santa Paula Peak Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for home development and road construction. Since these fills are considered in general to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Areas with Sufficient Existing Geotechnical Data

Logs of geotechnical boreholes drilled into alluviated canyon floors within the Santa Paula Peak Quadrangle were not found during the course of this study.

Areas with Insufficient Existing Geotechnical Data

Young Quaternary deposits in the Santa Paula Peak Quadrangle consist largely of fluvial and alluvial fan sediments in and along canyon slopes and mountain fronts. In large part, the sand-clay content of these deposits depends on the lithology of the bedrock being eroded within the source area for any particular drainage basin. Geologic mapping by Dibblee (1990) shows that bedrock in the northern half of the quadrangle is predominantly sandstone, whereas in the southern half it is mainly shale. Consequently, young Quaternary deposits within Santa Paula Creek, Sisar Creek, and Timber Canyon, which drain the northern part of the quadrangle, contain an abundance of potentially liquefiable sand, whereas deposits in canyons that drain the southern part of the quadrangle, such as Adams, Fagan, and Orcutt, contain abundant non-liquefiable clay. The sand-rich deposits within the canyon floor and alluvial fan environments that historically have been saturated within 40 feet of the surface are designated "zones of required investigation."

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Santa Paula Peak 7.5-Minute Quadrangle, Ventura County, California

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Santa Paula Peak 7.5-Minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking) complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Santa Paula Peak Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area.

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared.

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area.

- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area.

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Santa Paula Peak Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Santa Paula Peak Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Santa Paula Peak Quadrangle covers approximately 62 square miles in southern Ventura County and includes the northernmost part of the City of Santa Paula and the unincorporated community of Sulphur Springs. The City of Santa Paula is located about 10 miles northeast of the county seat at Ventura. Approximately 25 square miles of area in the northern half of the quadrangle was not evaluated for zoning because it lies within Los Padres National Forest.

The northern part of the Santa Paula Peak Quadrangle is dominated by steep mountainous terrain of the Topatopa Mountains. The ridge crests of Sulphur Mountain and Santa Paula Ridge trend roughly east west across the center of the map area. The rugged southern slopes of Sulphur Mountain and Santa Paula Ridge occupy the southern half of the quadrangle. Elevations range from approximately 400 feet above sea level in the southern part of the map area to 6,367 feet in the northwest near Topatopa Bluff. Santa Paula Peak is 4,957 feet above sea level.

The most important drainage course in the quadrangle is Santa Paula Creek, which flows in a southerly direction through the Topatopa Mountains and between Sulphur Mountain and Santa Paula Ridge before its confluence with the Santa Clara River just south of the quadrangle. Major tributaries to Santa Paula Creek include east-flowing Sisar Creek, which drains the western Topatopa Mountains and eastern Upper Ojai Valley, East Fork and La Broche and Echo Falls canyons, which drain the Topatopa Mountains, and Anlauf Canyon and Mud Creek, which flow southwestward from Santa Paula Ridge. West of Santa Paula Creek, drainage from Sulphur Mountain flows south via Salt Marsh, Adams, and Fagan canyons to the Santa Clara River. East of Santa Paula Creek, drainage from Orcutt and Timber canyons flows south from Santa Paula Ridge to the Santa Clara River.

Access to the area is via State Highways 150 and 126. Highway 150 (Santa Paula – Ojai Road) follows Santa Paula Creek north from Santa Paula and then curves to the west near Sulphur Springs. Highway 126 is located just south of the quadrangle and is the major east-west transportation route along the Santa Clara River Valley. Access to less developed areas is provided by fire roads, ranch roads, and oil field roads.

Residential development is concentrated in the valley areas with scattered development in the canyons, on the hillsides, and along Sulphur Mountain Road on the crest of Sulphur Mountain. Other land use in the area includes oil drilling and production in the Ojai (Silverthread Area), Santa Paula, and Timber Canyon oil fields, cattle grazing, citrus and avocado orchards, parkland, campgrounds, and the campus of Thomas Aquinas College. The northern half of the quadrangle lies within Los Padres National Forest, which includes part of the Sespe Wilderness Area and the Sespe Condor Sanctuary.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface in the form of a digital topographic map. Within the Santa Paula Peak Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, prepared from the 7.5-minute quadrangle topographic contours based on 1947 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The primary source of bedrock geologic mapping used in this slope stability evaluation was obtained from the Dibblee Geological Foundation (Dibblee, 1990) and digitized by CGS staff. The same map was also used for the Quaternary surficial geology, which is discussed in detail in Section 1 of this report. Landslide deposits were deleted from the digital map so that the distribution of bedrock formations and the landslide inventory would exist on separate layers for the hazard analysis. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to the development and abundance of landslides was noted.

Bedrock units in the Santa Paula Peak Quadrangle range from early(?) Eocene to Pleistocene. A continuous sequence of Eocene clastic marine deposits is exposed in a series of folds across the northern half of the quadrangle in the upper plate of the San Cayetano Fault. The oldest geologic unit mapped in the quadrangle is the early (?) to middle Eocene Juncal Formation, which crops out in the northwestern corner of the quadrangle. The Juncal Formation primarily consists of olive gray to dark gray micaceous shale and siltstone (Tjsh) with thin interbeds of light gray to light brown arkosic sandstone. Sandstones (Tjss) of the Juncal Formation are generally hard, light gray, fine- to medium-grained, and form prominent ledges, dip slopes, and strike ridges.

The middle to late Eocene Matilija Sandstone conformably overlies the Juncal Formation and is composed of light brown to mottled pale green arkosic sandstone (Tma) that is well-indurated, fine- to medium-grained, and thick-bedded to massive with thin partings and interbeds of gray micaceous shale. Several separately mapped units within the Matilija Sandstone include: a gray micaceous shale and siltstone unit with thin interbedded sandstone layers (Tmash), interbedded tan sandstone and micaceous shale and siltstone (Tmasl), and a hard white sandstone with thin interbeds of shale (Tmaw). Conformably overlying the Matilija Sandstone is the late Eocene Cozy Dell Shale, which consists of dark gray, well-indurated, locally fissile, argillaceous to silty micaceous shale (Tcd) with minor interbedded sandstone, and separately mapped lenses of light brown to gray-green arkosic sandstone with minor interbeds of micaceous shale (Tcdss).

The Cozy Dell Shale is conformably overlain by marine to transitional strata of the late Eocene Coldwater Sandstone. The Coldwater Sandstone consists of hard, light brown and light gray to white, thick-bedded, well-indurated, fine- to coarse-grained, arkosic sandstone (Tcw) with minor interbeds of greenish gray siltstone and shale, and local oyster-shell beds. Also included in the Coldwater Sandstone is a separately mapped unit (Tcwsh) composed of greenish-gray siltstone and shale with interbeds of light brown sandstone.

Eocene marine strata are overlain by late Eocene to early Miocene non-marine deposits of the Sespe Formation (Tsp), which are exposed in the northeastern quarter of the quadrangle in the Bear Heaven Syncline (Dibblee, 1990). The Sespe Formation consists of alluvial fan, floodplain, and deltaic deposits of maroon, red, and green silty shale and claystone interbedded with pale reddish gray, friable to poorly indurated sandstone and pebble-cobble conglomerate. In adjacent quadrangles, the Sespe Formation is overlain conformably by transitional to marine deposits of the Vaqueros Sandstone and Rincon Shale.

Miocene and younger strata are exposed in the southern half of the quadrangle south of the San Cayetano Fault. Siliceous organic marine deposits of middle to late Miocene Monterey (Modelo) Formation and late Miocene Sisquoc Shale crop out along the crest, northern slopes, and uppermost southern slopes of Sulphur Mountain in the Sulphur Mountain anticlinorium (Dibblee, 1990). The Monterey Formation is divided into three members in the map area. These members include a lower shale unit (Tml) composed of soft, fissile to punky clay shale with interbeds of hard siliceous shale and thin limestone beds, an upper shale unit (Tm) consisting of thin-bedded, hard, platy to brittle siliceous shale, and a white-weathering diatomaceous shale (Tmd). The Sisquoc Shale (Tsq) consists of light gray to gray-brown, silty shale or claystone that is locally siliceous and diatomaceous.

Sisquoc Shale is overlain by clastic marine deposits of the Pliocene Pico Formation (Tp), which are exposed on the southern slopes of Sulphur Mountain and Santa Paula Ridge and in a fault-bounded sliver northeast of Sulphur Mountain between the Sisar and San Cayetano faults. The Pico Formation consists of blue-gray, massive to bedded siltstone and silty shale with minor light brown sandstone and pebbly sandstone. Dibblee (1990) has also mapped an upper unit within the Pico Formation named the Mudpit Claystone Member (QTpm), which consists of massive to poorly bedded soft, crumbly claystone and mudstone with lenses of sandstone and conglomerate.

In the southeastern corner of the quadrangle, marine and transitional strata of the Plio-Pleistocene Las Posas Sand (QTlp) intertongues with and overlies the Mudpit Claystone. Las Posas Sand is composed of light brown, friable, fine-grained sandstone and siltstone that commonly contains shell fragments and also includes lenses of pebble-cobble conglomerate (QTlc). Non-marine strata of the Plio (?)-Pleistocene Saugus Formation (QTs) overlie and interfinger with the Las Posas Sand. Saugus Formation locally consists of poorly consolidated alluvial cobble-boulder conglomerate and thin beds of sandstone.

Quaternary surficial deposits cover the floors and margins of the larger canyons that drain the Topatopa Mountains, Sulphur Mountain, and Santa Paula Ridge. These deposits consist of Pleistocene old alluvial fan, alluvial-valley, and stream-terrace deposits (Qof, Qog, and Qog) and Pleistocene to Holocene young alluvial fan, alluvial-channel, and alluvial-floodplain deposits (Qf, Qg, and Qa). Isolated remnants of older terrace deposits also occur on the rugged slopes south of Santa Paula Ridge. Pleistocene to Holocene landslide deposits (Qls) are widespread throughout the Santa Paula Peak Quadrangle. Landslide deposits are discussed in more detail in a following section of this report.

Structural Geology

The Santa Paula Peak Quadrangle lies within the central Ventura Basin in the Transverse Ranges geomorphic province. Rocks in this region have been folded into a series of predominantly west-trending anticlines and synclines associated with thrust and reverse faults. This deformation was caused by regional north-south compression, which began during the late Pliocene and continues today (Yeats, 1989). Regional crustal shortening due to this compression is largely accommodated by the San Cayetano Fault and associated folds and flexural-slip faults in the Santa Paula Peak Quadrangle (Keller and others, 1982). To the west of the quadrangle in the Ojai Valley area, shortening is taken up by a blind-thrust fault and associated folding (Namson and Davis, 1988; Huftile, 1991).

The most important structural feature in the Santa Paula Peak Quadrangle is the San Cayetano Fault, an active, north-dipping reverse fault that extends along the north flank of Ventura Basin from the east end of Ojai Valley to Piru. It displaces Tertiary and Quaternary rocks with as much as 9 kilometers of stratigraphic separation (Rockwell, 1988). The trace of the San Cayetano Fault trends roughly east-west across the center of the Santa Paula Peak Quadrangle and is included in the Official Earthquake Zone prepared by CGS (DOC, 1986; Smith, 1977). Eocene to Oligocene rocks in the upper plate of the San Cayetano Fault are folded into a series of west-northwest-trending synclines and anticlines and have been thrust over Miocene and younger rocks to the south.

Major structural elements in the southwest quarter of the Santa Paula Peak Quadrangle, south of the San Cayetano Fault, include the Sisar Fault, Sulphur Mountain anticlinorium, South Sulphur Mountain Fault, and Sulphur Mountain homocline. Miocene strata form the Sulphur Mountain anticlinorium, which is complexly folded and has overturned limbs on both of its flanks. The Sisar Fault is a south-dipping thrust fault that extends along the north side of Sulphur Mountain and is believed to have formed as a backthrust above the main blind thrust fault (Huftile, 1991). The South Sulphur Mountain Fault is a north-dipping reverse fault that forms a pop-up structure along the south side of the crest of Sulphur Mountain (Huftile, 1991). Upper Miocene and Plio-Pleistocene strata form the south-dipping Sulphur Mountain homocline and northern flank of the Santa Clara Syncline in the southwestern corner of the quadrangle.

In the southeastern quarter of the quadrangle, steeply dipping Plio-Pleistocene strata on the northern flank of the Santa Clara Syncline are overlain unconformably by late Pleistocene to Holocene alluvial fans that extend down from the San Cayetano Fault into Orcutt and Timber canyons. These fan deposits are cut by eight parallel faults with south side up that show normal displacement where bedding is overturned and reverse displacement where bedding is right side up (Keller and others, 1982). From north to south, the four main faults, which are known collectively as the Orcutt/Timber Canyon faults, are called the Thorpe, Orcutt, Culbertson, and Rudolph faults (Keller and others, 1982). These faults are believed to be bedding-plane faults that undergo displacement during flexural-slip folding of the Santa Clara Syncline (Keller and others, 1982). Although these faults are not considered to be significant earthquake sources, they do have the potential for ground rupture and, therefore, the surface traces of these faults are included in the Official Earthquake Zone prepared by CGS (DOC, 1986; Kahle, 1985).

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Santa Paula Peak Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping (Morton, 1972; 1976). Landslides were mapped at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the landslide zoning as described later in this report. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

Landslides are widespread throughout the Santa Paula Peak Quadrangle, especially where relatively weak, fine-grained sedimentary rocks have been deformed by folding and faulting. Landslides in the area range from minor surficial failures resulting from soil and rock creep, rock fall, earth and debris slumps, earth flows, and debris flows to large rotational and translation landslides, some of which are relatively old and deeply eroded. Large ancient translational and rotational landslides are common in the folded sequence of Eocene clastic rocks in the upper plate of the San Cayetano Fault.

Several large ancient landslides have been mapped along the flanks and nose of the Sulphur Mountain anticlinorium within the complexly folded shale of the Monterey Formation. Landslide identification is somewhat difficult in this area because some of the suspicious-looking topography and anomalous bedding attitudes may be the result of tight folding rather than mass movement.

Numerous large ancient composite landslides also occur in the relatively weak Pico Formation strata on the southern slopes of Santa Paula Ridge, especially in the Mud Creek Canyon area. In addition, there are many relatively young earth slides, debris slides, and earth flows mapped adjacent to and within the older bedrock slide complexes. Many landslide headscarps and debris deposits on Santa Paula Ridge occur within or adjacent to strands of the San Cayetano Fault and are probably related to tectonic processes.

Small-scale surficial ("thin-skin") failures including soil creep, earth slides, and earth flows are pervasive in the Pico Formation on the southern slopes of Sulphur Mountain west of Santa Paula Creek. Relatively larger translational rock slides and earth slides are also common in the area. In many cases, the lower portions of these slide masses yield earth flows.

Because it is not within the scope of the Act to review and monitor grading practices to ensure past slope failures have been properly mitigated, all documented slope failures, whether or not surface expression currently exists, are included in the landslide inventory.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Santa Paula Peak Quadrangle geologic map were obtained from the County of Ventura Public Works Agency and Earth Systems Consulting in Ventura (see Appendix A). The locations of rock and soil samples taken for shear testing within the Santa Paula Peak Quadrangle are shown on Plate 2.1. Shear test information from the Matilija, Ojai, and Santa Paula quadrangles were considered for several geologic formations for which little or no shear test information was available within the Santa Paula Peak Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean or median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For each geologic strength group (Table 2.2) in the map area, the average shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

The following geologic map units were subdivided further, as discussed below: Tjsh, Tjss, Tma, Tmash, Tmasl, Tmaw, Tcd, Tcdss, Tcwsh, Tsp, Tsq, and QTs.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, were used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, but greater than 25 percent (4:1 slope), the area was marked as a potential adverse bedding area.

The following formations, Tjsh, Tjss, Tma, Tmash, Tmasl, Tmaw, Tcd, Tcdss, Tcwsh, Tsp, Tsq, and QTs, which contain interbedded sandstone and shale, were subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material strength dominates where bedding dips into a slope (favorable bedding) while fine-grained material strength dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for these formations are included in Table 2.1.

Existing Landslides

As discussed later in this report, the criteria for landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the landslide zone of required investigation. Therefore, an evaluation of shear strength parameters for existing landslides is not necessary for the preparation of the zone map. However, in the interest of completeness for the material strength map, to provide relevant material strength information to project plan reviewers, and to allow for future revisions of our zone mapping procedures, we have collected and compiled shear strength data considered representative of existing landslides within the quadrangle.

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used. Within the Santa Paula Peak Quadrangle, only one direct shear test of landslide slip surface materials was obtained, and this is presented in Table 2.1.

SANTA PAULA PEAK QUADRANGLE SHEAR STRENGTH GROUPS							
	Formation Name	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1						Tjsh(fbc) Tjss(fbc) Tma(fbc) Tmash(fbc) Tmasl(fbc) Tmaw(fbc)	38*
GROUP 2	Tcw Tm QTlp af	3 3 3 2	34/34 33/32 34/38 34/34	34/34	478/340	Tcwsh(fbc) QTlc QTs(fbc)	34
GROUP 3	Qof Qf	2 2	30/30 30/30	30/30	478/355	Tjsh(abc) Tjss(fbc) Tma(abc) Tmash(abc) Tmasl(abc) Tmaw(abc) Tcd(fbc) Tcdss(fbc) Tsp(fbc) Tml Tsq(fbc) Qog, Qa, Qg	30
GROUP 4	Tsq(abc) Tp QTpm Qoa	2 8 3 19	28/28 25/28 27/22 27/27	27/28	503/319	Tcd(abc) Tcdss(abc) Tcwsh(abc) Tsp(abc) Tmd QTs(abc)	27
GROUP 5	Qls	1	17/17	17/17	500/500		17

* = phi values selected based on data from surrounding quadrangles

abc = adverse bedding condition, fine-grained material strength

fbc = favorable bedding condition, coarse-grained material strength

Formations name abbreviations from Dibblee (1990)

Table 2.1. Summary of the Shear Strength Statistics for the Santa Paula Peak Quadrangle.

SHEAR STRENGTH GROUPS FOR THE SANTA PAULA PEAK 7.5-MINUTE QUADRANGLE				
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**	**GROUP 5**
Tjsh(fbc)	Tcw	Tjsh(abc)	Tcd(abc)	Qls
Tjss(fbc)	Tcwsh(fbc)	Tjss(abc)	Tcdss(abc)	
Tma(fbc)	Tm	Tma(abc)	Tcwsh(abc)	
Tmash(fbc)	QTlp	Tmash(abc)	Tsp(abc)	
Tmasl(fbc)	QTlc	Tmasl(abc)	Tmd	
Tmaw(fbc)	QTs(fbc)	Tmaw(abc)	Tsq(abc)	
	af	Tcd(fbc)	Tp	
		Tcdss(fbc)	QTpm	
		Tsp(fbc)	QTs(abc)	
		Tml	Qoa	
		Tsq(fbc)		
		Qof, Qog		
		Qa, Qf, Qg		

Table 2.2. Summary of Shear Strength Groups for the Santa Paula Peak Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the “ground shaking opportunity.” For the Santa Paula Peak Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10 percent probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8
Modal Distance:	2.5km to 3.8km
PGA:	0.79g to 1.07g

The strong-motion record selected for the slope stability analysis in the Santa Paula Peak Quadrangle is the Corralitos record from the 1989 magnitude 6.9 (M_w) Loma Prieta earthquake (Shakal and others, 1989). This record had a source to recording site distance of 5.1 km and a peak ground acceleration (PGA) of 0.64. Although the parameters from the Corralitos record do not fall within the range of the probabilistic parameters, this record was considered to be sufficiently conservative to be used in the stability analyses. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.08, 0.13, and 0.23g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Santa Paula Peak Quadrangle.

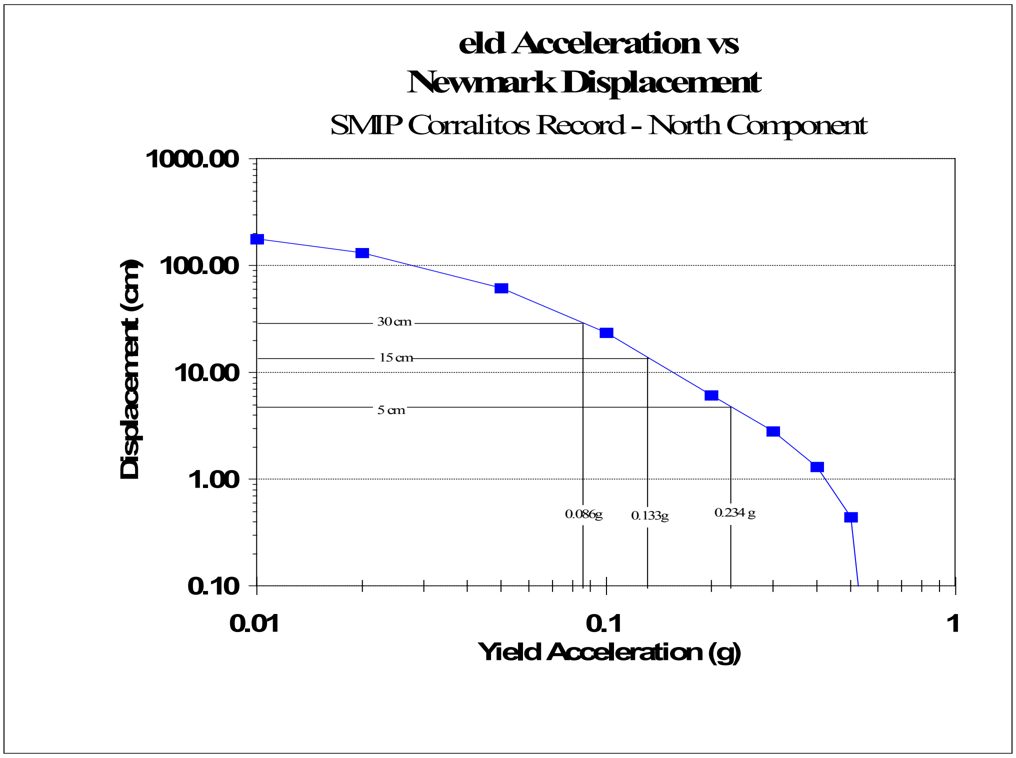

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1989 Loma Prieta Earthquake Corralitos Record. Record from California Strong Motion Instrumentation Program (CSMIP) Station 57007.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where **FS** is the Factor of Safety, **g** is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.08g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)

2. If the calculated yield acceleration fell between 0.08 g and 0.13 g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)

3. If the calculated yield acceleration fell between 0.13 g and 0.23g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)

If the calculated yield acceleration was greater than 0.23g, Newmark displacement of less than 5cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3). Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

SANTA PAULA PEAK QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Strength Group (Average Phi)	HAZARD POTENTIAL (Percent Slope)			
	Very Low	Low	Moderate	High
1 (38)	0 to 53%	53 to 62%	62 to 69%	> 69%
2 (34)	0 to 41%	41 to 52%	52 to 57%	> 57%
3 (30)	0 to 33%	33 to 44%	44 to 48%	> 48%
4 (27)	0 to 26%	26 to 37%	37 to 41%	> 41%
5 (17)	0 to 8%	8 to 17%	17 to 22%	> 22%

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Santa Paula Peak Quadrangle. Values in the table show the range of slope gradient (expressed as percent slope) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 5 is included in the zone for all slope gradients greater than 8 percent. (Note: The only geologic unit included in Geologic Strength Group 5 is

Qls, existing landslides. They have been included or excluded from the landslide zones on the basis of the criteria described in the previous section)

2. Geologic Strength Group 4 is included for all slopes steeper than 26 percent.
3. Geologic Strength Group 3 is included for all slopes steeper than 33 percent.
4. Geologic Strength Group 2 is included for all slopes steeper than 41 percent.
5. Geologic Strength Group 1 is included for all slopes greater than 53 percent.

This results in approximately 62 percent of the area mapped in the quadrangle lying within the earthquake-induced landslide hazard zone for the Santa Paula Peak Quadrangle.

ACKNOWLEDGMENTS

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AIR PHOTOS

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NASA (National Aeronautics and Space Administration) 04689; Flight 94-002-02; January 22, 1994; Frames 446-453, 535-545, 622-632, 639-650, 734-740, 744-750; Black and White; Vertical; scale 1:15,000.

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USGS (U.S. Geological Survey) Area A; February 27, 1998; Frames 1A-12 to 1A-15; Color; Vertical; scale 1:24,000.

APPENDIX A
SOURCES OF GEOLOGIC MATERIAL STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
County of Ventura, Public Works Department	**36**
Earth Systems Consulting	**12**
Total Number of Shear Tests	**48**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Santa Paula Peak 7.5-Minute Quadrangle, Ventura County, California

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (DOC, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology [California Geological Survey], and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10 percent probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

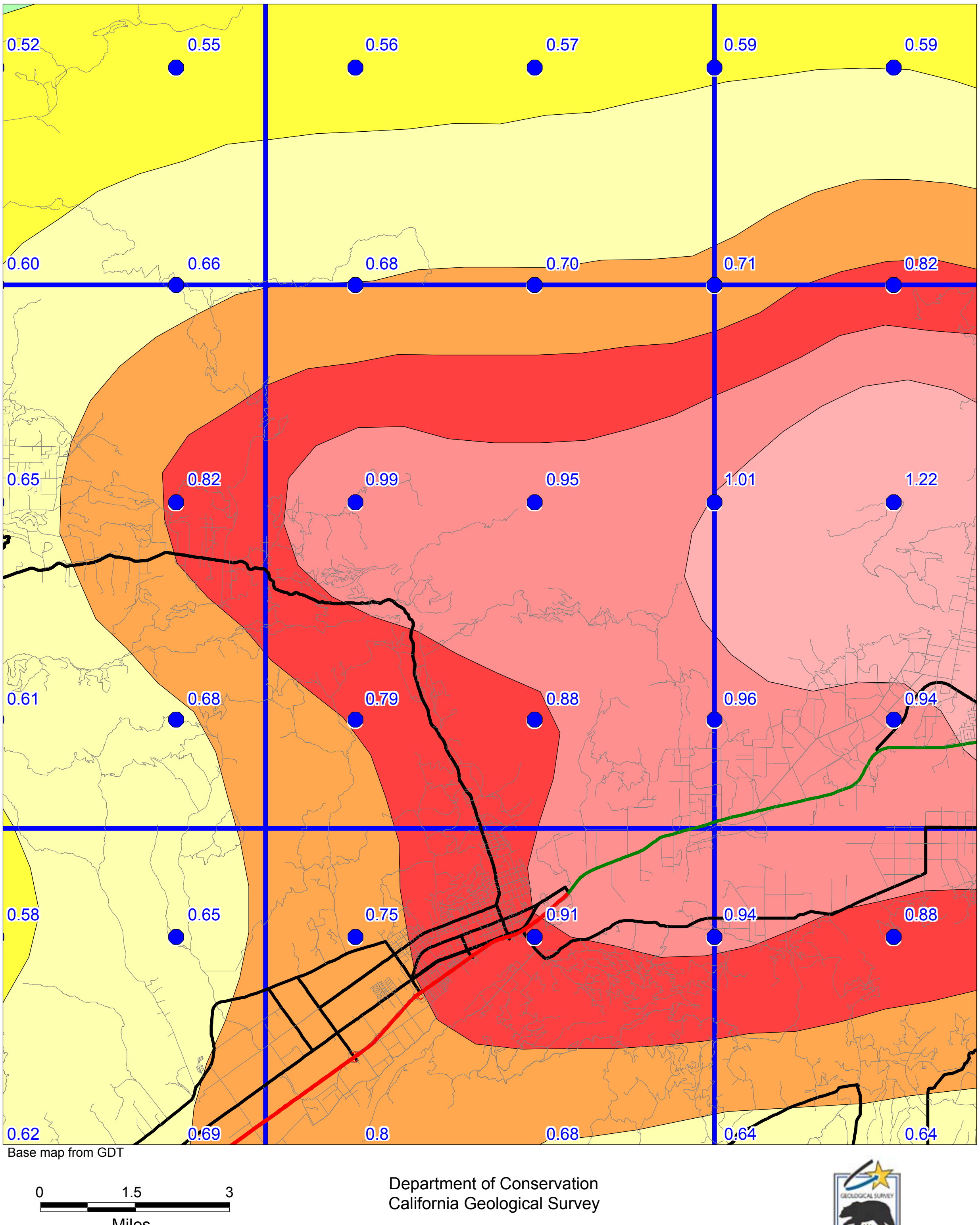
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight

SANTA PAULA PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Department of Conservation
California Geological Survey

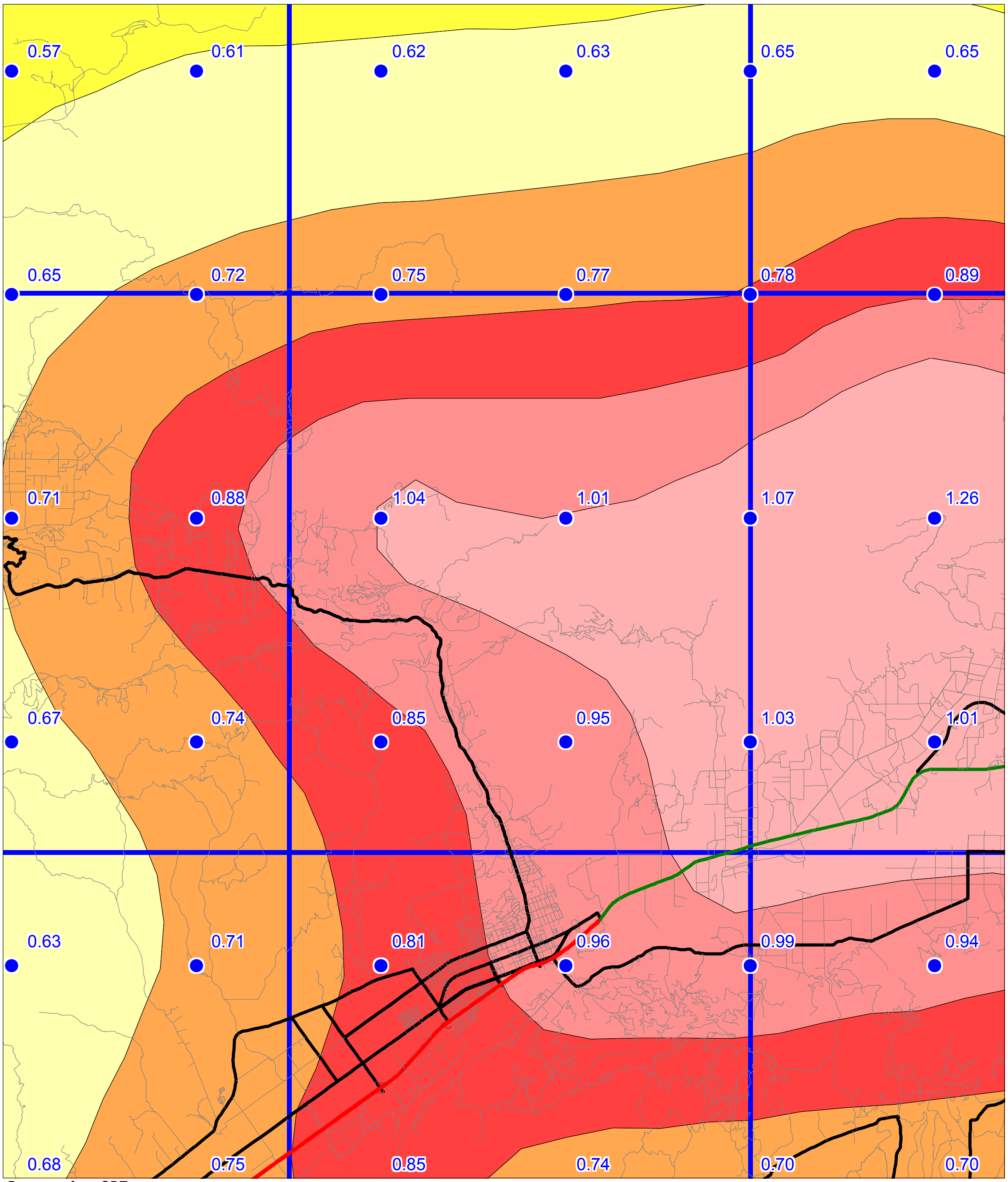
Figure 3.1

SANTA PAULA PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

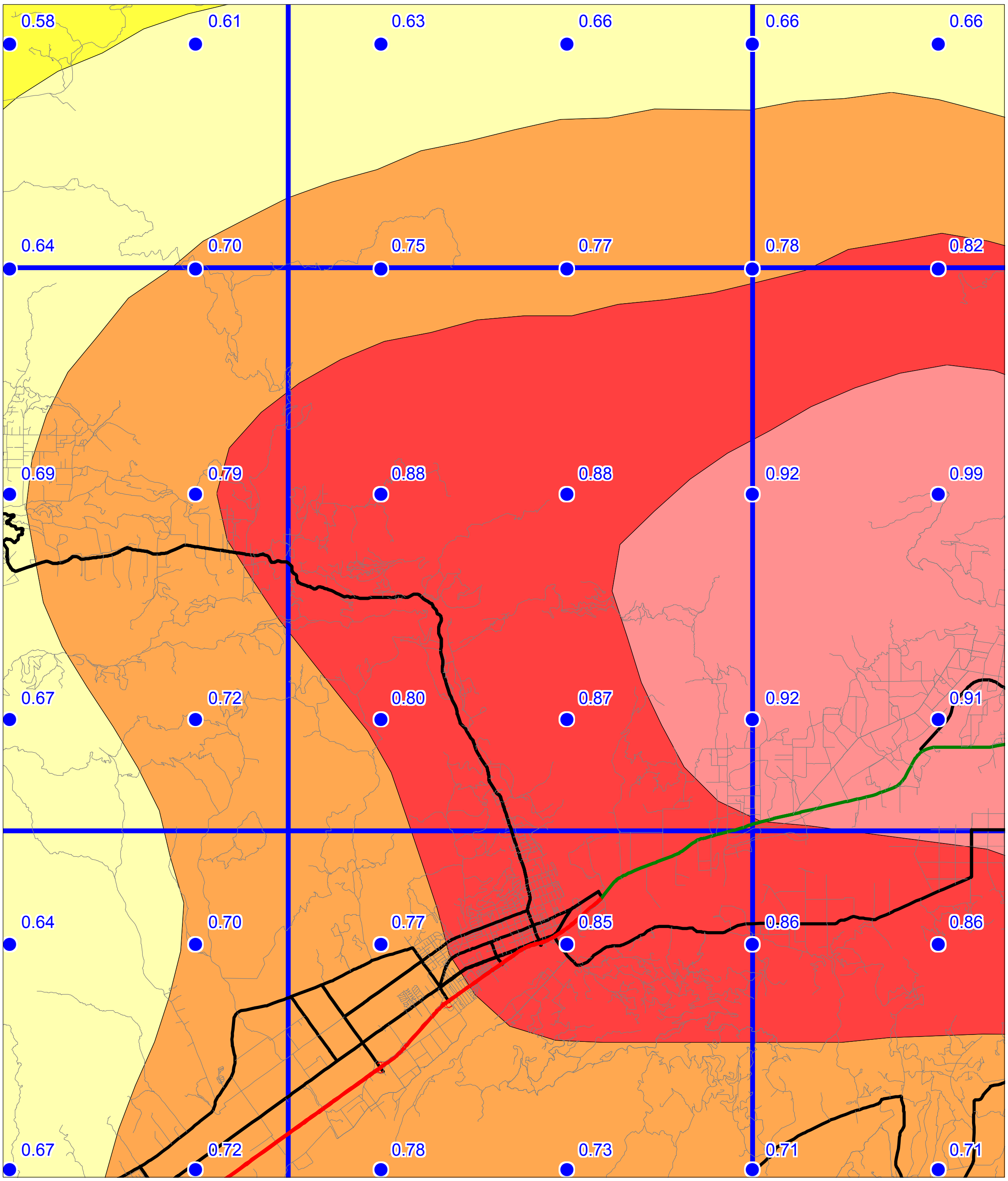
Department of Conservation
California Geological Survey

Figure 3.2

SANTA PAULA PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)
1998

ALLUVIUM CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.3

adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10 percent probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

SANTA PAULA PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

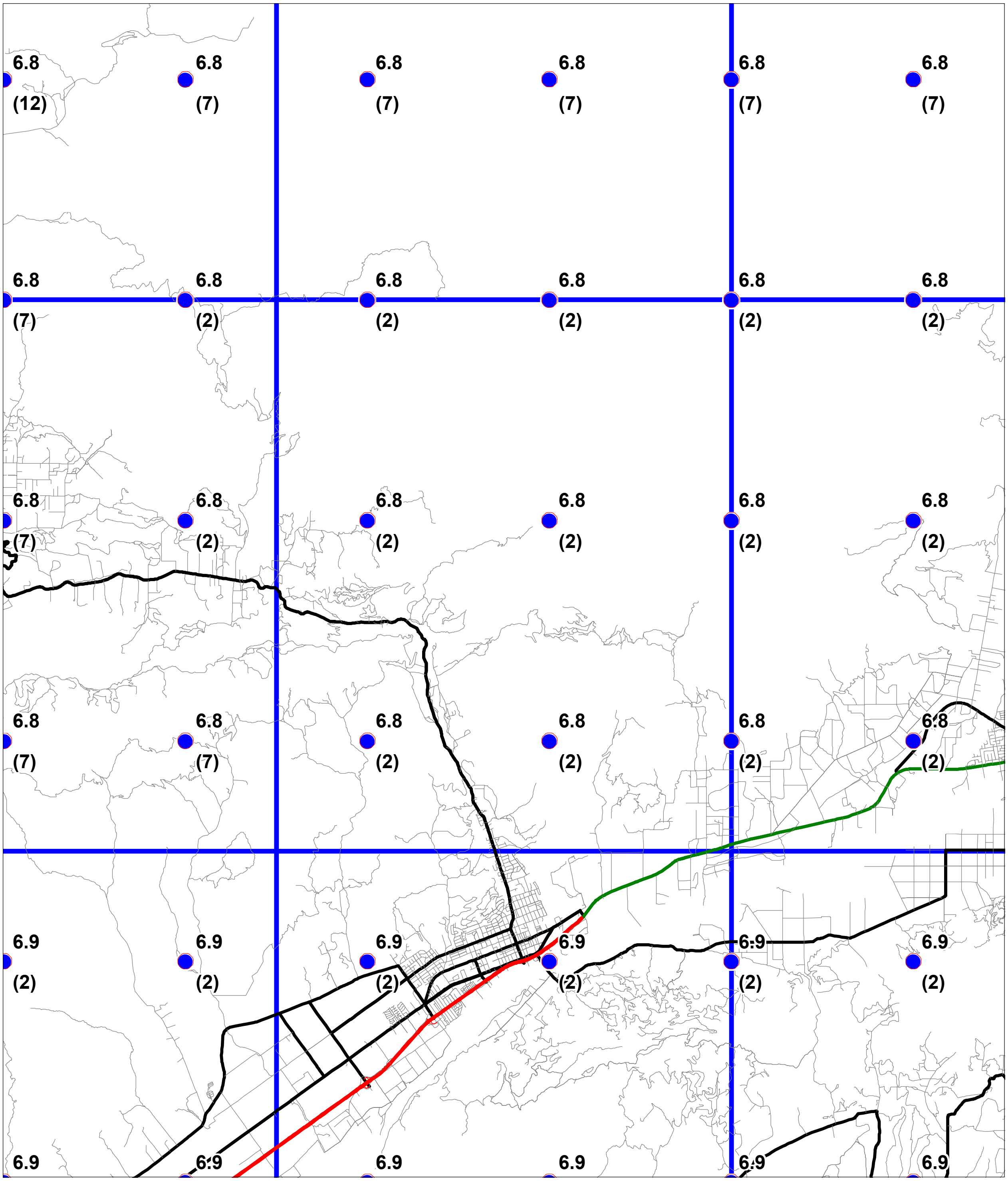
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



Base map from GDT

0 1.5 3

Miles

Department of Conservation

California Geological Survey

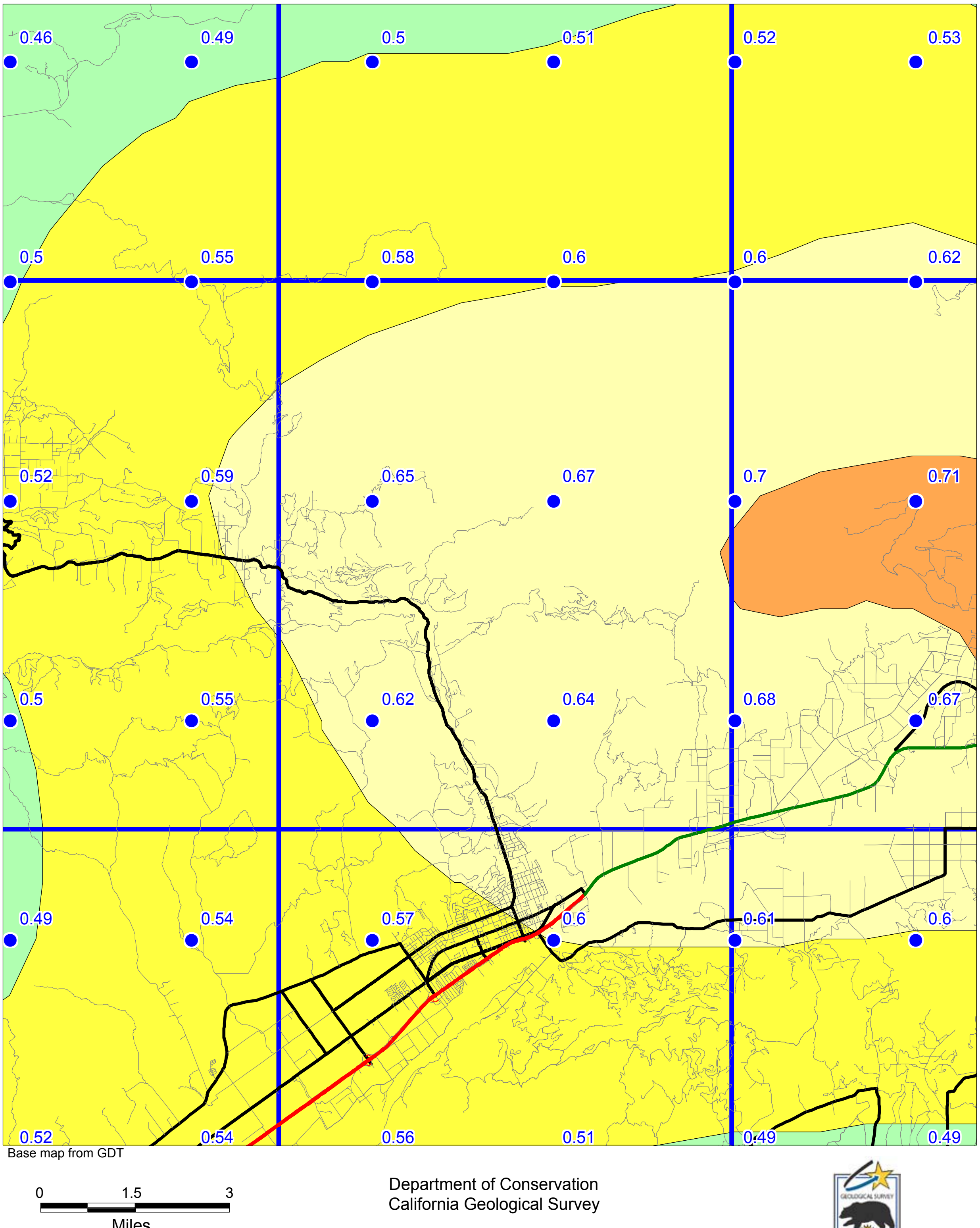
Figure 3.4

SANTA PAULA PEAK 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g) FOR ALLUVIUM

1998

LIQUEFACTION OPPORTUNITY



Department of Conservation
California Geological Survey

Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50 percent of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the "importance" or sensitivity of the proposed building with regard to occupant safety.

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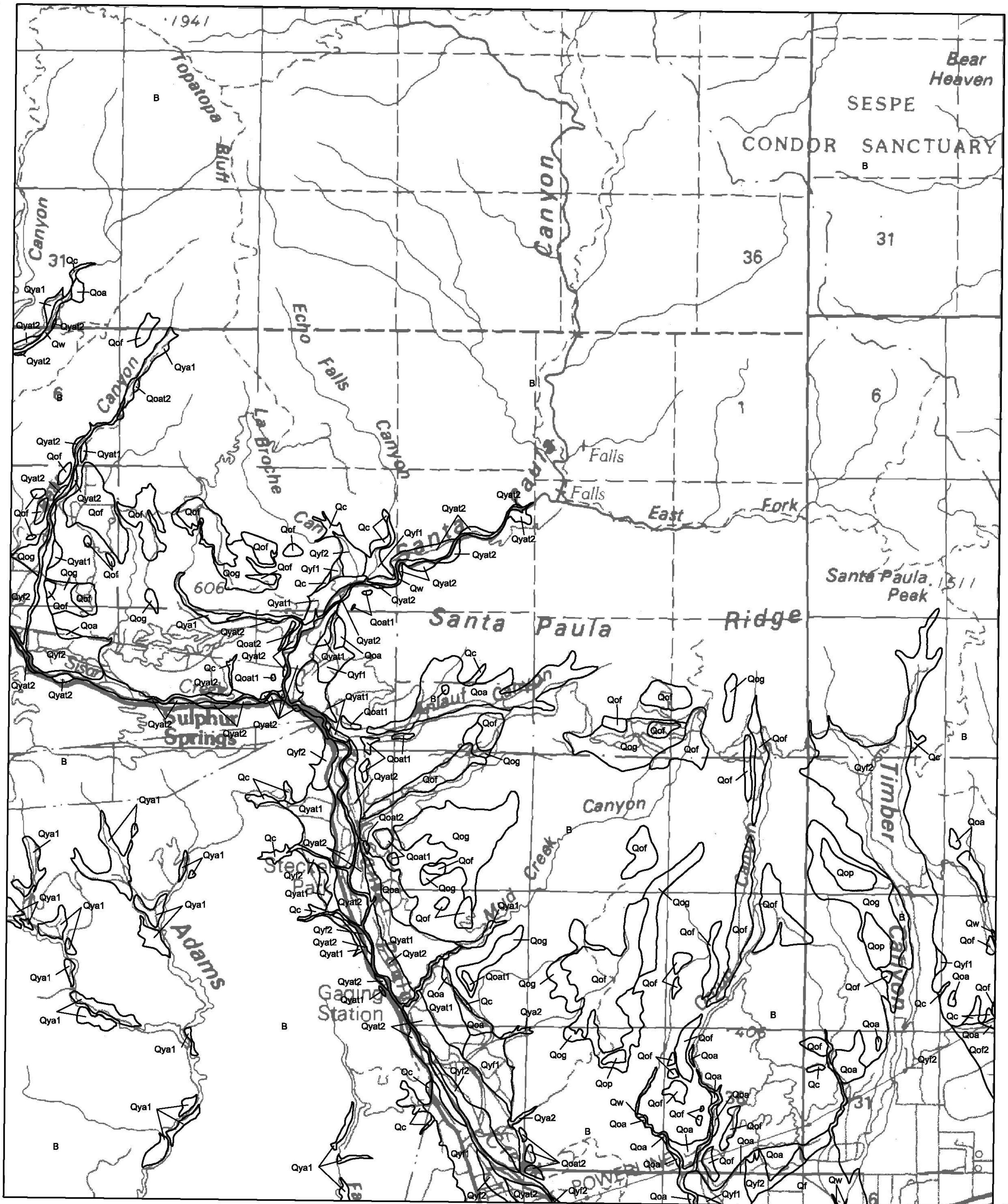
119°07'30"
34°30'00"



34°22'30"
119°00'00"

Base map enlarged from U.S.G.S. 30 x 60-minute series

SANTA PAULA PEAK QUADRANGLE

SCALE

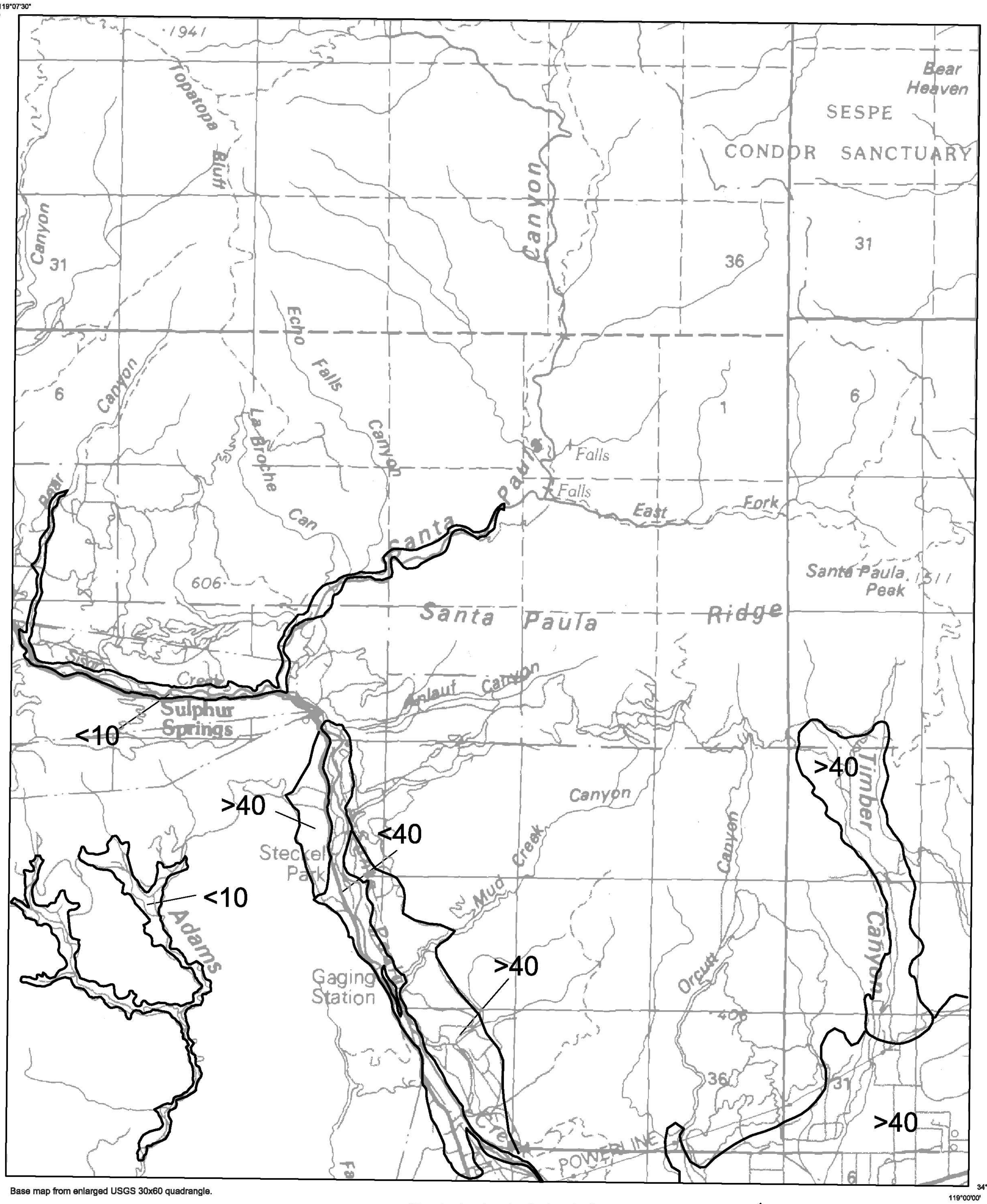
1 .5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

N

B = Pre-Quaternary bedrock.

See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of geologic units.

Plate 1.1 Quaternary geologic map of the Santa Paula Peak 7.5-Minute Quadrangle, California (William Lettis & Associates, 2000).



SANTA PAULA PEAK QUADRANGLE

SCALE

1 MILE

7000 FEET

1 KILOMETER

N

Alluviated Valley

>40 Historically shallowest depth to ground-water (in feet) within basin or canyon

Plate 1.2 Historically shallowest ground-water depths in alluviated areas of the Santa Paula Peak 7.5-Minute Quadrangle, California

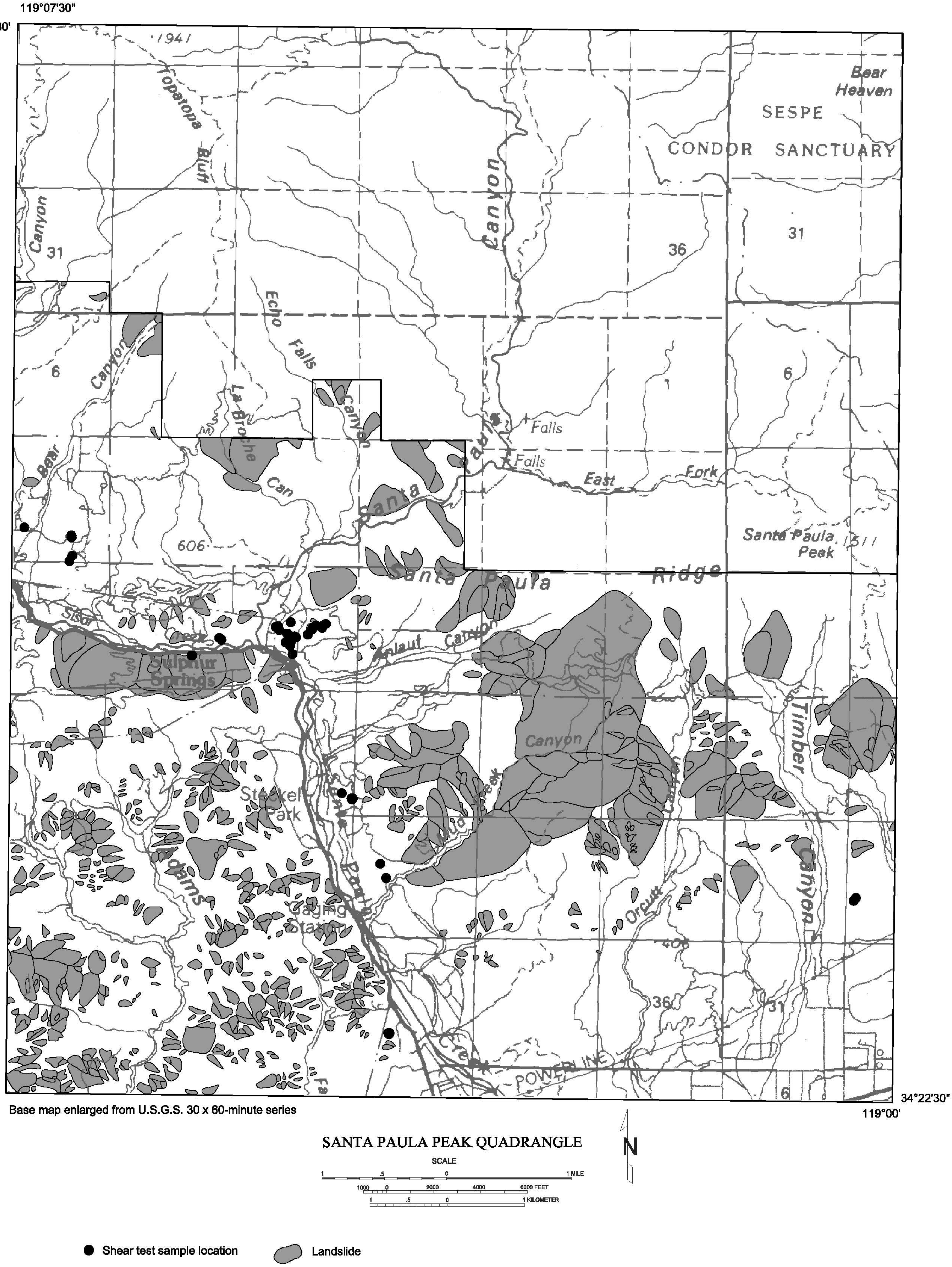


Plate 2.1 Landslide inventory, shear test sample locations, and areas of significant grading, Santa Paula Peak 7.5-Minute Quadrangle, California.